Photon-Counting CT Binning and Electronic Noise Reduction

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Photon counting is a special application in computed tomography (CT). Unlike conventional CT technology, which collects images by incorporating average attenuation values when several x-ray photons strike energy-integrating detector arrays, the photon-counting systems produce their images by accurately attributing the magnitude of energy associated with each x-ray striking the next generation detectors.[1,2] This multienergy detection scheme allows spectral imaging that discriminates for tissue composition and physiological function, as well as detail.[3]

The principal mechanisms of photon-counting CT are semiconductor materials that allow incoming information to be directly converted at the detector plate, detector geometry that integrates a small pixel-size design, the weighting of the incoming photons by energy level, and the capacity to sort those energies according to several predesignated thresholds.[4-6] Although each feature improves spatial resolution when optimized, the sorting or binning of x-ray energy by threshold affords operators the chance to reduce noise inherent in a CT system's electronics.

Photon-counting detectors mark a paradigm shift in CT. With minimal radiation dose, the systems detail the body's tiniest bones and redefine calcium scoring and coronary CT angiography.[4,5] For example, to best examine blood flow through a cardiac vessel, coronary stent struts and calcium buildup might be subtracted irrespective of the gating strategy implemented.[3-5,7] Vulnerable plaques also might be characterized.[8] In 2021, with all major vendors close to commercializing their platforms, a dual-source scanner called the *Naeotom Alpha* (Siemens) became the first clinical photon-counting CT system marketed in the United States.[1,2,9]

Building on the underlying knowledge of the radiologists, cardiologists, and technologists who participate in cardiovascular CT, this review highlights similarities between electronic noise reduction in photon-counting CT and noise filtration in devices used for cardiac rhythm management. Specifically, comparisons are made to routine practices conducted by clinicians to ensure proper functionality of cardiac implantable electronic devices (CIEDs) to better understand how sensing the heart's electrophysiological activity yields practical tips and tricks for appreciating the reduction of electronic noise in photon-counting CT.

Examples of Cardiac Implantable Electronic Devices

Along with pacemakers, implantable cardioverter defibrillators promote sinus rhythm. Certain defibrillators and pacemakers coordinate—or synchronize—the left and right ventricles throughout the cardiac cycle to achieve sinus rhythm. These CIEDs are commonly referred to as *biventricular pacers* whether the unit is a defibrillator or a pacemaker.[10-13] To optimize performance of implantable pacers and defibrillators, clinicians conduct tests at regular intervals, which include evaluations of electrical interference, to determine how well devices detect or sense a patient's rhythm during select timing sequences. In comparison, CIEDs known as *loop recorders* only track arrhythmias, and tests on loop recorders only consider electrical interference.[13]

Comparisons Between CIEDs and Photon-Counting CT

When examining sensing of CIEDs, clinicians focus on the sensitivity calibration of a device. Oversensing means any amount of activity (noise) can terminate a paced event, whereas undersensing means the device might not pace when needed. Device sensitivity can be modified and programmed based on outcomes, including review of the device's activity log and the patient's rhythm history.[14] Distinguishing sensing indexes of CIEDs can be compared with earmarking noise-reduction thresholds in photon-counting CT (see **Figure 1**).

Crosstalk, or far-field sensing, also might be examined during checkups.[12,14] Because a larger signal is associated with the larger mass of the ventricles, the most common example of far-field sensing occurs with ventricular activity detected by an atrial-placed lead.[13] This far-field phenomenon represents sharing of electrical noise (interference) originating from outside a detection zone (see **Figure 2**). The juxtaposition of a CIED electrogram and a photon-counting CT sectional view to compare the use of blanking periods for far-field sensing with photon-counting CT correction strategies for charge-sharing artifacts is shown in **Figure 3**.

Photon-Counting CT Binning and Noise Reduction

Although the number of x-rays per energy bin associated with photon-counting detectors is less than the total number of x-rays exiting the patient, critical trade-offs occur between the number, width, and placement of bins relative to ratios for signal and noise.[15] For example, fewer x-ray photons sorted into bins in detectors possessing a relatively high bin number compromises image quality because of decreasing signal strength. However, cancelling out noisy, low-energy photons simultaneously allows cancellation of a CT system's electronic interference, thus improving overall resolution.[13,15,16] Patients are direct benefactors of this technology because it reduces noise from the energy domain, which adds to traditional attempts to improve spatial and temporal quality (ie, image- or projection-based denoising and iterative reconstruction), and it negates the need to increase radiation dose.[15] Multienergy data from photon-counting CT enhance tissue characterization and differentiation without a need to dispense iodinated contrast media.[3,5,15]

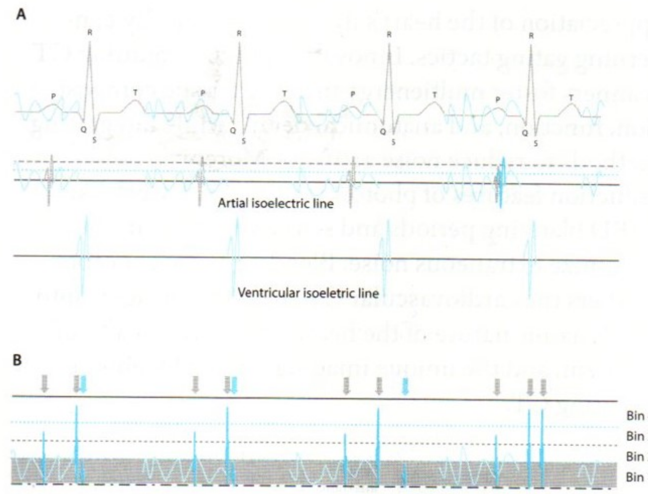

Figure 1. *Comparison of cardiac implantable electronic device (CIED) sensing indexes with noise-reduction thresholds in photon-counting computed tomography (CT). A. Pacemaker sensitivity adjusted in the setting of atrial fibrillation. The top isoelectric line illustrates atrial fibrillation via surface electrocardiography. The atrial isoelectric line shows that the first 3 beats were sensed properly despite noise (wavy lines) from the fibrillating atria; therefore, the device did not pace the heart. A proper index per calibration (grey dashed line) denotes the potential threshold required to sense activity. A device-originated atrial beat ensued (fourth beat, darker blue) because intrinsic activity fell outside the threshold. Improper calibration (blue dotted line) permits oversensing of nonproductive, electronic noise, which causes the device to withhold pacing when otherwise needed. The bottom isoelectric line indicates ventricular sensing. B. Photon-counting detector compartmentalizing x-ray energy levels and electronic noise. Sectional view of photon-counting detector CT containing 4 bins, or thresholds, for indexing different energy strengths (arrows). Bin 1 is reserved for x-ray photons with low-energy (blue arrows) and the CT system's electronic noise (wavy lines). All information from bin 1 is neglected during image construction. Images courtesy of the author.*

Conclusion

Radiologists, cardiologists, and technologists experienced in cardiovascular CT develop a powerful appreciation of the heart's dynamics, especially concerning gating tactics. Innovative photon-counting CT scanners foster multienergy imaging (tissue composition, function, and anatomical detail) while integrating methods to reduce noise artifacts. Moreover, noise-reduction features of photon-counting CT work like CIED blanking periods and sensitivity measures to minimize extraneous noise. Blending these concepts furthers the cardiovascular CT operator's insights into the dynamic nature of the heart, the overall health of a patient, and the unique imaging offered by photon-counting CT.

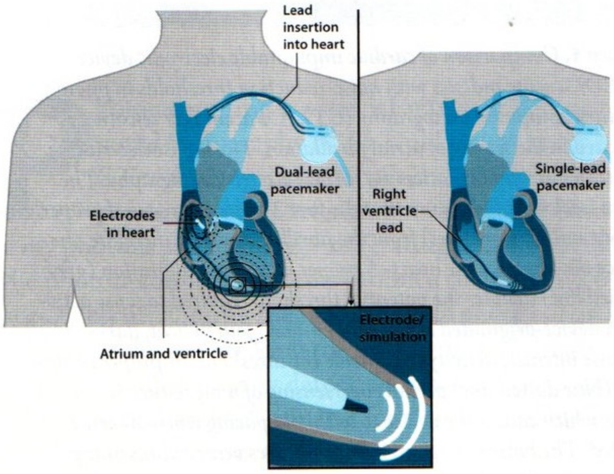

Figure 2. *Sensing and pacing activity depicted for an atrial- and a ventricular-placed lead. Waveforms from ventricular electrophysiological activity emanate into the atrial lead's detection zone. This phenomenon, observed on the CIED electrogram as far-field sensing, adds unwanted noise to the system. Public domain image reprinted with permission from Wikimedia Commons under the Creative Commons Public Domain Mark 1.0 license. creativecommons.org/publicdomain/mark/1.0/*

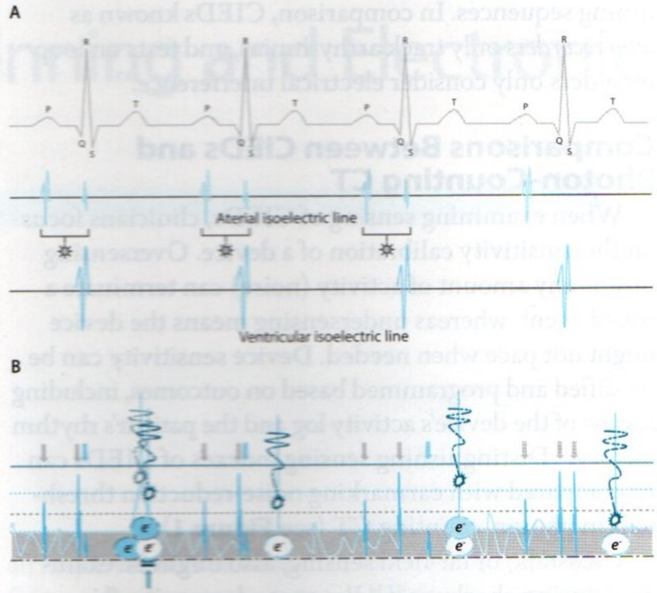

Figure 3. *A. CIED electrogram showing sinus rhythm (top line) and far-field sensing (asterisks) in the atrial lead from ventricular activity. Although far-field sensing disrupts a device's atrial timing sequence, it can be rectified by adjusting the blanking period associated with the atrial lead. Blanking denotes a period after atrial sensing in which subsequent activity is invisible to the CIED. Blanking periods are similar to absolute refractory periods associated with cardiac and skeletal muscle. B. Charge sharing of electrons (e⁻) compared with information from in-line trajectories on sectional view of a direct conversion CT photon-counting detector. Charge sharing (blue e⁻) degrades image quality. Corrections for electron sharing of charge between adjacent detector pixels involve communication between the pixels, such that summation of activity gets attributed to the detector pixel collecting the most charge (up arrow). Images courtesy of the author.*

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